A QUANTITATIVE STUDY OF THE DIMENSIONS AND GROWTH OF THE PALATE IN THE NORMAL INFANT AND IN THE INFANT WITH GROSS MALDEVELOPMENT OF THE UPPER LIP AND PALATE

A THESIS
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA

BY

WILLIAM THOMAS PEYTON

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
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The Dimensions and Growth of the Palate in the Normal Infant and in the Infant with Gross Maldevelopment of the Upper Lip and Palate

A QUANTITATIVE STUDY

WILLIAM T. PEYTON, M.D.
MINNEAPOLIS

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The investigator should consider himself fortunate if he finds a field of investigation in which opinions and estimates have long been expressed and in which more recently the fundamentals have been subjected to debate in a tone of controversy. He should be especially pleased if he takes up this subject with the intention of applying the comparatively newer quantitative methods of analysis and finds that these methods have not yet been tried in this particular field, although they are well suited for it.

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* A thesis submitted to the faculty of the Graduate School of the University of Minnesota in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

* From the Department of Surgery, University of Minnesota.

Investigation of the quantity and position of the tissue in children with cleft palate answers the foregoing hypothesis. For years opinions have been expressed to the effect that there is a deficiency of tissue in cases of congenital clefts of the upper part of the face and jaw. Brophy (1907) brought controversy when he said that all tissues are present. Since this statement was made, it has been refuted by opinions based on clinical estimates or made on a few measurements, taken for the most part on the facial skeleton rather than directly on the palate.

The solution of this question, namely the amount and disposition of the tissue in the cleft palate, is essential to the selection of plans for the surgical repair of these clefts. Fundamentally, there are three principal types of operation typified by the operations of Krimer, Warren and Brophy for clefts of the alveolar process and palate, all of which have undergone many modifications by other surgeons. The operation of Krimer, better known as the flap operation of Lane, is similar to other plastic flap operations in general surgery used to restore defects which are due to loss of tissue. The Warren-von Langenbeck operation

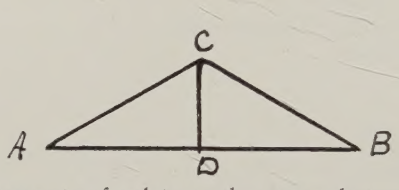

Fig. 1.—Measurements of palate as they were determined by Alkan.

is similar to other plastic operations performed for the restoration of defects caused by separation, but without loss of tissue. The Brophy operation is based on the assumption that the cleft is due to lateral separation of normally developed tissue.

This study is undertaken with no attempt to prove any expressed opinion or to support a personal theory.

LITERATURE

THE NORMAL PALATE

Quantitative growth of the normal palate has been subjected to only superficial investigation. Alkan measured the width and length of the hard palate with a calipers, and calculated the height. He took the diameter or width (fig. 1, *AB*) between the first and second premolar and also between the first and second molar teeth from the inner margin of the gum, except in new-born children where only one measurement of the width was taken, and this at approximately the middle of the alveolar process. From this same point on each side of the alveolar process, he took measurements *AC* and *CB* (fig. 1) where *C* is located

at approximately the center of the arch of the palate. The height of the palate *CD* was then calculated from the known values for *AC, CB* and *AB*.

The material measured by Alkan included thirty-five infants from 1 to 9 days of age and also one child 90 days old. No trend of growth is demonstrated in these measurements. The averages were as follows: width, 2.7 cm.; length, 3.2 cm., and height, 1.2 cm. He computed width-height indexes to compare with similar indexes computed for adult

TABLE 1.—*Dimensions of Palates of Children as Determined by Alkan*

Age, Days	Sex		Skull			Palate		
	Male	Female	Length, Cm.	Width, Cm.	Width of Face, Cm.	Width, Cm.	Length, Cm.	Height, Cm.
1	..	1	11.7	8.8	7.0	2.6	3.4	1.5
1	1	..	12.1	9.1	7.3	2.6	3.1	1.0
1	..	1	11.9	9.7	7.1	2.8	3.4	1.05
1	..	1	12.0	9.4	7.2	2.9	3.4	1.3
2	..	1	9.7	8.0	5.85	2.1	3.2	0.8
2	..	1	11.6	9.0	6.5	2.5	3.2	1.2
3	..	1	11.6	9.5	7.3	2.9	3.5	1.3
3	..	1	11.2	8.3	6.6	2.6	3.3	1.3
3	..	1	12.0	8.8	7.1	2.8	3.0	0.95
3	..	1	11.5	9.3	7.1	2.7	3.1	1.4
3	..	1	11.9	9.0	7.1	2.4	3.4	1.3
3	..	1	11.8	9.7	6.9	2.4	2.9	1.3
4	1	..	10.7	8.6	6.4	2.3	3.1	0.9
4	..	1	12.0	8.9	6.8	2.4	3.3	0.8
4	1	..	11.6	8.8	7.2	2.7	3.1	1.4
4	1	..	13.0	9.8	7.3	3.0	3.1	1.1
4	..	1	11.3	8.5	6.9	3.0	2.9	1.0
4	..	1	11.7	9.2	7.4	2.8	3.3	1.4
5	1	..	11.6	9.3	6.8	3.1	3.5	0.9
5	1	..	11.5	9.3	7.2	2.9	3.2	1.3
5	1	..	11.9	9.0	6.6	2.6	3.0	1.1
5	1	..	11.6	8.6	6.7	2.8	3.0	1.3
6	..	1	11.3	9.3	7.2	2.6	3.6	1.2
6	..	1	10.5	7.6	6.5	2.5	3.4	1.1
6	1	..	12.0	9.0	7.2	2.6	3.2	1.3
6	1	..	11.4	8.8	7.2	2.8	3.3	1.3
7	1	..	12.2	9.6	7.3	3.0	3.3	0.95
7	1	..	11.7	9.3	7.5	2.8	3.0	1.1
8	1	..	11.9	9.0	6.7	2.5	3.2	1.1
8	..	1	11.7	8.9	6.9	2.7	3.0	1.1
8	1	..	13.1	9.4	7.2	2.9	3.5	1.3
8	1	..	12.3	10.4	7.3	3.0	3.4	1.3
9	..	1	11.4	9.1	6.5	2.6	3.0	1.0
9	..	1	11.9	8.9	7.0	2.6	3.1	1.3
9	..	1	12.1	9.6	7.4	2.9	3.2	1.3
90	1	..	11.2	8.7	6.2	2.8	2.9	1.1

material and concluded that the palate of the new-born infant is relatively short and high. His measurements are recorded in table 1.

Denzer took some measurements on the palates of children under 1 year of age by making impressions of the palate, and from these impressions he made dental casts. Measurements were read from the dental cast with the surveying apparatus of Stanton. This surveying apparatus is an orthoscopic apparatus with which it is possible to locate and read the position of a point in three dimensions. It is therefore used to make orthographic projections from models and for measuring elevations. For width, Denzer took the widest point of the alveolar process, and for height the highest point of the arch of the palate.

These are the same measurements which have been taken in the present investigation. The results as determined by Denzer are recorded in tables 2 and 2a. The averages of his measurements were width, 30.9 mm. and height, 8.79 mm.

W. K. Connell read a paper before the Anatomical Section of the British Medical Association in 1922 on the "Form of the Palate in Children." He took an impression of the upper dental arcades in plasticine and studied the variations in shape and determined in normal and abnormal conditions the changes which took place during growth,

TABLE 2.—*Dimensions of Palates of Children as Determined by Denzer*

Age	Greatest Width, Mm.	Greatest Height, Mm.	Age	Greatest Width, Mm.	Greatest Height, Mm.
3 months	32.5	8.7	5 months	32.0	8.2
4 weeks	27.5	8.0	5 months	30.5	10.0
4 weeks	29.0	8.0	5 months	30.0	8.6
12 days	30.0	11.3	5 months	28.5	9.0
6 weeks	28.5	8.0	6 months	31.5	9.7
6 weeks	30.0	9.9	6 months	30.5	8.6
6 weeks	30.5	9.6	6 months	28.5	7.2
7 weeks	28.0	7.4	7 months	31.5	7.7
2 months	28.0	9.5	7 months	30.0	8.7
2 months	27.0	7.7	7 months	32.0	8.1
2 months	31.0	10.1	8 months	33.5	8.3
2 months	28.5	7.5	8 months	31.5	9.9
3 months	32.0	7.4	9 months	35.0	8.0
3 months	32.5	8.7	9 months	32.5	7.1
4 months	33.0	9.7	10 months	36.0	9.3
4 months	32.0	9.4	11 months	30.0	9.5
4 months	30.0	8.7	11 months	34.0	9.4
4 months	34.0	9.5	11 months	33.0	8.1
4 months	32.5	10.0			

TABLE 2a.—*Average Dimensions at Different Ages*

Age	Number of Cases	Greatest Width, Mm.	Greatest Height, Mm.
1 to 3 months, inclusive	13	29.4	8.7
4 to 6 months, inclusive	12	31.0	9.0
7 to 11 months, inclusive	11	32.6	8.5
All children under 1 year	29	30.9	8.89

also the relation of the size of the arch to the state of development of the child. He found that, "There was no connection between the size of the child and the shape of the palate, nor was there any alteration in the arcade in children with adenoids."

Buser measured the width, height and length of the palate in 514 persons all of whom were over 15 years of age. He used special instruments, with which he took readings directly from the palate, without the use of impressions or casts. Two measurements of width were taken: one at the first premolar tooth and the other at the first molar tooth. Height was taken as the highest point of the arch of the palate in relation to the occlusive surface of the teeth. Length of the palate was taken as a direct line measurement from the space between

the medial incisors in front to the posterior edge of the hard palate. Division according to sex was made in all of his tables, and still further divisions according to age were made in some of his tables. The data on persons from 15 to 17 years of age are included in one table, and on all above this age are included in the second table. The male palate in each of its dimensions is approximately 1 mm. greater than those of the female, according to his observations, and there is a slight increase in size after the fifteenth year. The approximate dimensions of the adult palate taken from the tables of Buser are as follows: width (at first molar), 48 mm.; height, 21 mm. and length, 54 mm. Table 3 is copied from Buser.

Shaw measured the width, height and length of the palate in adults. His results were: height, 14.2 mm.; length, 50.8 mm., and width (at first molar), 35.5 mm.

TABLE 3.—*Dimensions of Palates as Determined by Buser*

Age of Individuals Measured	Dimension	Males		Females	
		No. Cases Measured	Average Size, Mm.	No. Cases Measured	Average Size, Mm.
15 years of age and over	Palate width, first premolar	257	37.5	257	36.0
	Palate width, first molar....	213	48.6	186	46.9
	Palate height.....	257	21.6	257	20.2
	Palate length.....	254	54.7	257	52.7
15 to 17 years of age.....	Palate width, first premolar	17	37.7	75	35.7
	Palate width, first molar....	12	47.9	53	46.3
	Palate height.....	17	20.8	75	19.6
	Palate length.....	17	53.2	75	52.8
18 years of age and over	Palate width, first premolar	240	37.4	182	36.1
	Palate width, first molar....	201	48.6	133	47.2
	Palate height.....	240	21.7	182	20.4
	Palate length.....	237	54.8	182	52.7

Gustav Franke measured a large series of palates at different ages. The width of the palate, measured at the posterior border of the first molar tooth, as determined by Franke is as follows: 2 to 7 years, 41.1 mm.; 8 to 13 years, 45.9 mm.; 14 to 21 years, 48 mm.; 22 to 29 years, 49.4 mm.; 30 to 50 years, 50.2 mm. The length of the palate, according to Franke's figures, was 26.8 mm. at birth and 52.8 mm. in the adult, or approximately a twofold increase between birth and maturity.

THE MALDEVELOPED PALATE

Quantitative studies of growth and of the amount and disposition of tissue in the cleft palate are meager, but there are many opinions based purely on clinical observation or on the writings of others.

The measurements which have been taken to estimate the quantity of tissue or the spread of tissues in the palate have for the most part been taken indirectly; either skull measurements were taken to determine the breadth of the facial portion of the skull, or to determine the dis-

tance between the hamular process, or between other similar bony points of the facial skeleton. These measurements have been made largely on the macerated skull rather than on the living child.

Some measurements made by Kirkham on skulls in the Hunterian Museum of London are given in table 4. The greatest abnormality in dimensions of cleft palates according to these figures, is in the distance between the hamular processes.

Skull measurements, made by Wardill on museum specimens with and without cleft palate, together with similar measurements taken by Veau and quoted by Wardill are recorded in table 5. Wardill concluded from these measurements of the bony parts that there is associated with

TABLE 4.—*Skull Dimensions as Determined by Kirkham*

Age	Distance Between Posterior Palatine Foramina, Mm.	Distance Between Hamular Processes, Mm.	Distance From Hamular Process to Posterior Palatine Foramina, Mm.	Distance Between Tuberosities, Mm.
Normal children				
Birth	17.5	18.0	6.0	27.0
2 months	19.5	22.0	5.5	30.0
10 months	20.0	ns*	ns	30.5
8 months	22.0	22.5	7.5	29.5
12 months	23.0	23.0	9.0	33.5
19 months	22.5	ns	ns	35.0
2 years	21.5	ns	ns	33.0
2¼ years	23.0	ns	ns	37.5
2½ years	23.5	24.5	9.0	37.0
3 years	22.0	24.0	9.0	37.5
3½ years	22.5	27.0	10.0	36.5
4 years	22.0	29.0	12.0	39.0
5 years	25.0	27.5	12.0	36.0
5¾ years	15.0	28.0	11.0	37.5
6 years	22.5	ns	ns	37.5
8 years	27.0	32.0	12.0	40.0
Normal				
Average adult	30.0	34.0	12.0	54.0
Cleft palate				
Adult	40.0	41.0	12.0	54.5
Nubian woman	40.0	46.0	10.5	55.0

* Hamular process was missing and therefore measurement was not taken.

cleft palate a small but definite increase in the transverse diameter of the nasopharynx.

Izard has determined that there is a rather constant relationship in the adult between the transverse diameter of the palate and the bizygomatic diameter of the facial portion of the skull. This relationship is approximately 1 : 2, but it apparently does not hold for infants in which the bizygomatic distance is considerably less than twice the transverse diameter of the palate. The transverse diameter of the palate and the bizygomatic diameter of the skull, as determined by Ruppe, are included in table 6. Ruppe concluded that for infants these measurements of skulls with cleft palate are quite similar to those of normal skulls, and therefore, that there is no evidence of separation of the maxilla in the cleft palate.

Superimposing tracings of the alveolar curves of the maxilla and mandible, J. E. Thompson concluded that the maxillary tuberosities have not been much displaced in cleft palate, since he found the maxillary process at this point seldom more than 1 mm. greater than that

TABLE 5.—*Measurements Compiled by Wardill*

Nasion to Occipital Point, Mm.	Transverse Diameter, Mm.	Transverse Hamuli, Mm.	Nasion to Occipital Point, Mm.	Transverse Diameter, Mm.	Transverse Hamuli, Mm.
180.0	153.0	38.5	176.0	148.0	35.0
162.0	149.0	43.0	171.0	133.0	28.0
156.0	133.5	32.0	160.0	133.0	33.0
127.0	117.0	27.0	151.0	124.5	23.0
123.0	103.0	24.0	148.0	124.0	26.0
122.0	101.0	24.5	133.5	117.0	23.5
121.0	102.0	31.0	120.0	92.0	21.0
117.0	111.0	31.0	112.0	90.0	18.5
101.0	82.0	23.0	107.0	84.0	22.0
100.0	94.0	26.0	103.0	90.0	19.0
93.5	88.0	24.5	99.0	82.5	19.5
93.0	83.0	25.0	96.0	82.0	17.5
*Glabella to Occipital Point, Mm.			*Glabella to Occipital Point, Mm.		
175.0	128.0	41.0	178.0	149.0	34.0
187.0	150.0	42.0	190.0	147.5	36.0
187.0	145.0	43.5	195.5	191.5	32.5
169.0	125.0	39.5	180.0	141.0	30.0

* Glabella to occipital point substituted here for nasion to occipital point distance because in the skulls with cleft palate a large part of the calvarium had been removed.

TABLE 6.—*Skull Dimensions as Determined by Ruppe*

	Transverse Diameter of Palate, Mm.	Bizygomatic Diameter, Mm.	Twice the Bimaxillary Distance, Mm.
Skulls of normal infants.....	14	23	28
	16	26	32
	17	26	34
	17	30	34
	18	30	36
	19	33	38
	21	34	42
	25	46	50
	27	44	54
	27	48	54
	28	48	56
	33	56	66
	33	57	66
	35	62	70
Skulls of infants with cleft palate...	60	100	120
	48	85	96
	45	70	90
	32	78	64
	43	86	86
	40	66	80
	47	92	94
	50	82	100

of the mandible, but the most prominent curve of the alveolar processes he found 2 or 3 mm. displaced or spread.

Trendelenburg concluded that the facial portion of the skull is wider than normal when the palate is cleft. He took measurements on the width of the choanae, the distance between the infra-orbital foramen

and between the zygomaticomaxillary suture of each side on skulls with and without cleft of the palate, and found that these dimensions are greater in persons with cleft palate.

Alex Lindberg stated that measurements of normal patients and patients with cleft palate demonstrate the mesopharynx to be from 0.5 to 1.5 cm. greater in the latter.

Opinions based in part or entirely on observation, rather than measurement, are found in the literature on maldevelopments of the lip and palate. These opinions are readily divisible into two groups completely at variance with each other. In one group are those who believe that all the tissue is present, and in the other are those who believe there is an actual deficiency of tissue due to deficient development, arrested growth or atrophy. Outstanding among the former and apparently the first to press this opinion was Brophy (1907), who maintained that children who have congenital malformation of the palate, with rare exceptions, have the normal amount of tissue in the palate. Brophy maintained that when the margins of the cleft have been brought into contact, the upper jaw is then restored to its normal breadth and to its proper relation to the lower jaw. There are few exceptions, and he further said that other writers have been unconscious of the fact that as a rule the bones are not deficient in structure or incomplete in development.

Veau also expressed the belief that the parts are normal, or if less than normal, that they have between them the ability to reproduce the normal amount of palate tissue. He stated that they are developed as a normal palate, but that it becomes abnormal only because of lack of coalescence.

The opinion of the majority falls in the second group, which holds that there is not a normal amount of tissue in the cleft palate.

Arthur Keith (1909) quoted Brophy to the effect that there is no deficiency in the tissue of the cleft palate. But Keith stated that this was not the case in the specimens that he had examined. He examined the palates of three adults with clefts and found the clefts on the average 20 mm. wide; the average breadth of the palate was 64 mm., and this, he said, demonstrates that the bony parts of these palates were from 10 to 15 mm. less than normal. In new-born children, according to Keith, the deficiency affects the inner or marginal area of the palate but it does not amount to more than 3 mm. on each side. He admitted that he is not able to say whether or not the cleft continues to increase after birth, but judging from the width of the cleft of the adult palate, he concluded that they do not continue to separate at the rate after birth that they did before birth.

Winternitz is of the opinion that the halves of the cleft palate are rudimentary, and that their relative growth is not in proportion to that

of the oropharyngeal cavity, wherefore in later years the cleft is not only wider, but that this lack of development causes a relatively short soft palate after repair, and therefore is the cause of poor speaking function after repair. He is of the opinion that this lack of development in relation to the skull is especially marked in the soft palate.

According to Trendelenburg, there is a lack of normal development not only of the palate on the side of a unilateral cleft, but the growth of the entire jaw on this side is retarded. Failure to recognize the short side of the alveolar process as a part and not a complete half of the process is apparently the basis of this opinion.

Ernest Frazer said there is no question that an extra protrusion of the frontonasal region and elongation of its septal portion does occur, but it is possible that a certain amount of the appearance of protrusion is really due to a deficiency of the maxillary mass placed beside it. He is of the opinion that "accurate measurements, however, under many conditions are necessary in quantity."

Wardill, in speaking of the cleft palate, said, that there is less than the normal amount of soft tissue, and that this has been used to bridge an abnormally wide nasopharynx. J. F. Esser said that one should not forget that there is practically always a deficit of material.

COLLECTION OF DATA

MEASUREMENTS TAKEN

The data consist essentially of two parts: (1) general body and head measurements and (2) palate measurements. Weight and standing and sitting height were the general body measurements taken. Twenty-three head measurements were taken, but are not all incorporated in this report; seven of these head measurements were bilateral. Crown-heel length and fronto-occipital diameter are the only body and head measurements used in this report. The body and head measurements were taken in the usual manner. Details of procedures in obtaining those used in this study are given in the following paragraphs. Special technic for obtaining palate measurements were worked out, the details of which are subsequently given.

METHOD OF OBTAINING MEASUREMENTS

The crown-heel length was taken with the Martin anthropometer, the straight attachments being used, and the frontal-occipital diameter was taken with Martin curved arm calipers.

All the measurements on the palate were taken from dental casts and dental molds. Kerr perfection impression compound was used to make these dental casts. A dental tray could not be found on the market small enough to use in the first year of life. To obtain a suitable tray, an impression was made of the upper jaw of a new-born infant, and a dental tray was made up from this.

The impression compound was softened in warm water and applied to the palate on the dental tray; cold water on a sponge was applied to harden the material quickly before its removal from the mouth. These impressions were flowed up in dental plaster of paris in the usual manner to obtain a plaster of paris mold (dental cast) of the palate. One of the most difficult points to determine was the medial edge of the palate plate in cases with cleft. As a rule, however,

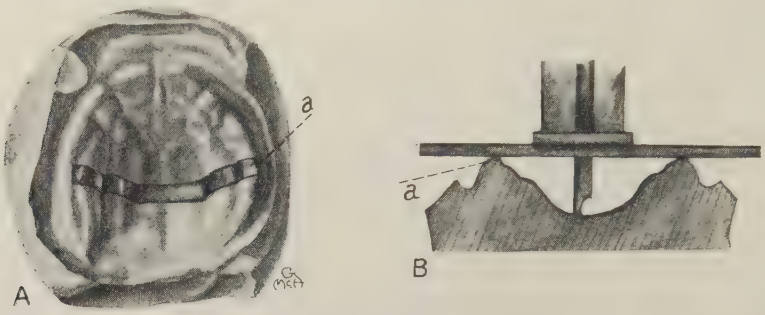

Fig. 2.—Method of taking the surface width and height of the normal palate. In *A*, the lead foil is applied at the widest part of the alveolar process to obtain the surface width of the palate. *B* is a cross-section of the palate to show the method of measuring the height of the palate. *a* shows measurement at the highest point of the alveolar process.

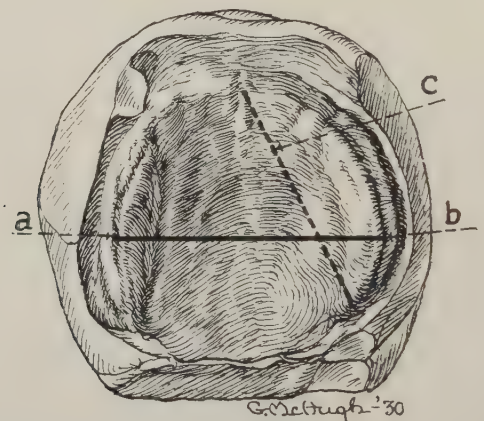

Fig. 3.—Measures taken for the normal palate: *a*, the widest transverse diameter of the palate measured to the highest point of the alveolar process (*b*); *c*, the chord of the alveolar process.

this was well demarcated by a line representing the transition from the squamous epithelium of the oral cavity to the ciliated epithelium of the nasal cavity.

Four dimensions common to both the normal and maldeveloped palate were taken, and in addition, the width of the cleft was read in the maldeveloped palates. Those common to both the normal and the cleft palate were: (1) widest transverse diameter, (2) surface width of palate, (3) height of palate and (4) the chord of the alveolar process which is referred to in the text as the length of

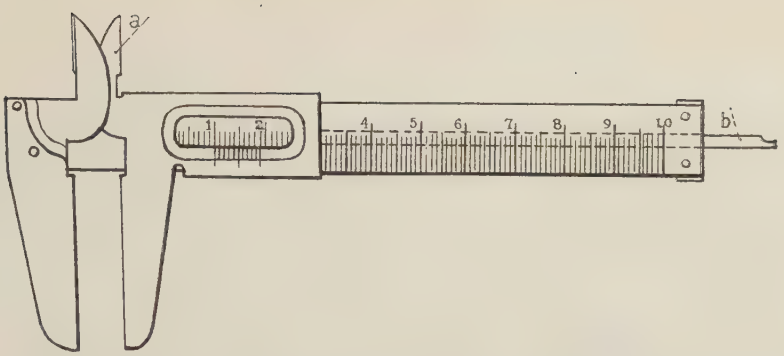

Fig. 4.—Instrument used for taking measurements on the palate: *a* indicates the blade used for measuring the width of the cleft, and *b*, the sliding bar used for measuring the height of the palate.

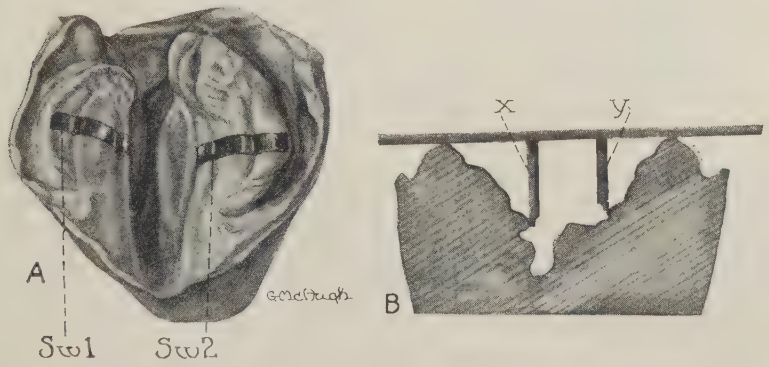

Fig. 5.—Method of taking the surface width and height of the palate in unilateral clefts of palate. In *A*, *Sw* indicates the surface width of the palate; Sw1 + Sw2 = total Sw. *B* is a cross-section of the palate; $\frac{X+Y}{2}$ = height of palate.

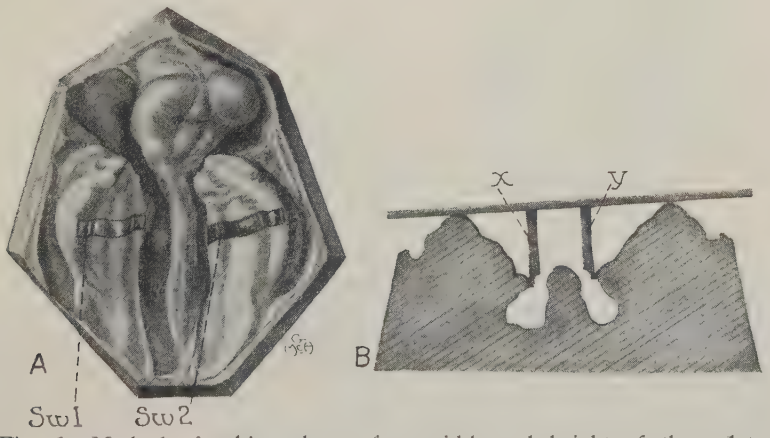

Fig. 6.—Method of taking the surface width and height of the palate in bilateral clefts of the palate. In *A*, Sw indicates the surface width of the palate; Sw1 + Sw2 = total Sw. *B* is a cross-section of the palate; $\frac{X+Y}{2}$ = height of palate.

alveolar process. The method of taking these measurements in the normal palate is illustrated in figures 2 and 3, and for the cleft palate in figures 4, 5, 6 and 7.

In general, the descriptive name designates what these measurements are, but the end-points utilized and the exact method of taking them is as follows: The widest transverse diameter of the palate was taken in approximately the coronal plane, using the middle of the alveolar process as end-points. The surface width

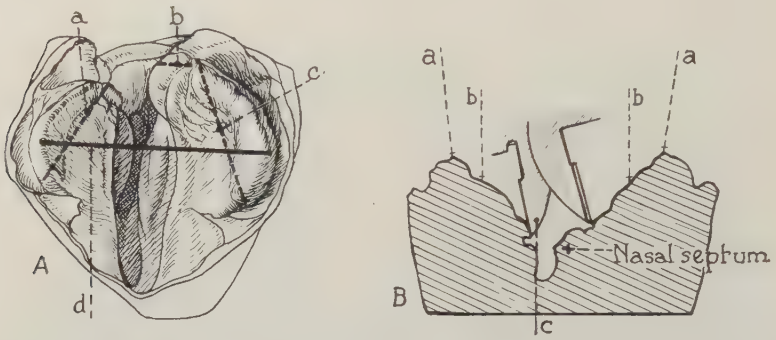

Fig. 7.—Measures taken for the widest transverse diameter, length of the alveolar process and the width of the cleft in unilateral clefts of the palate. In *A*, $a + b$, and *c* indicates the chords of the alveolar process; *d*, the widest transverse diameter of unilateral cleft palate. In *B*, *a* indicates the alveolar process of the palate; *b*, the plate of the palate, and *c*, the method of measuring the width of unilateral cleft palate.

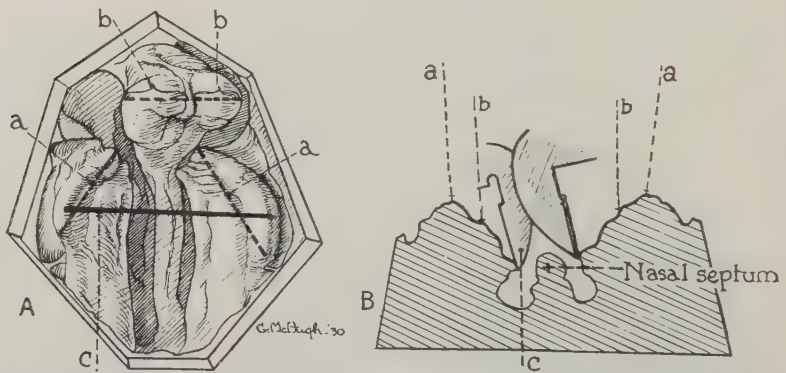

Fig. 8.—Measures taken for the widest transverse diameter, the length of the alveolar process and the width of the cleft in bilateral clefts of the palate. In *A*, $a + b$ indicates the chord of the alveolar process, and *c*, the widest transverse diameter of a bilateral cleft palate. In *B*, *a* indicates the alveolar process of the palate; *b*, the plate of the palate, and *c*, the method of measuring the width of a bilateral cleft palate.

of the palate was taken in approximately the same coronal plane as the widest transverse diameter and with the same end-points but in the following manner. Thin sheet lead was cut into strips from 1 to 2 mm. wide, and this strip pressed firmly against the palate so that it assumed the shape of the palate surface includ-

ing all its irregularities. After the strip had been so pressed into position, it was cut at the end-points of the measure, that is, where the strip passed over the mid-portion of the alveolar process. The strip was then removed, pressed out on a flat surface to remove all irregularities, and with a calipers this straight piece of metal was measured. This dimension is referred to as the surface width of the palate. In the cleft palate, two strips were used, one for each plate of the palate, and here the end-point for the medial edge of the plate was taken at the point of transition of the squamous epithelium of the oral cavity into the ciliated epithelium of the nasal cavity.

The height of the palate was taken by placing a rigid metal bar across the palate at its deepest portion, and the distance from the upper surface of this metal bar to the deepest point of the mold was read. The width of the transverse bar was subtracted from this reading and the remainder taken as the actual height of the arch of the palate. A true curvelinear measurement of the length of the alveolar process was not taken, but instead a straight line measurement, the arc of the alveolar process was measured to estimate its length. It was taken from the midpoint anteriorly to the posterior end of the alveolar process on each side. The measurement for each side was recorded separately, but the average of both sides has been used in this analysis. This measurement could not be taken directly on the short side of the unilateral clefts, nor directly on either side of the bilateral cleft, but was, in the unilateral cases, taken as the sum of the short side plus one-half the width of the premaxilla, and in the bilateral clefts as the length of one side plus one-half the premaxilla. The width of the cleft was taken with a calipers as illustrated in figure 3, at the point of the widest separation of the medial edge of the plates of the palate.

SELECTION OF MATERIAL

The material consists essentially of two groups, namely, normal children and maldeveloped children, each group covering approximately the same growth period.

Ninety-one normal children are included in this material, fifty-one of whom are females and forty are males. This division as to sex was entirely chance since no attempt was made at selection. In age they ranged from a new-born (premature) infant to a child 362 days of age and in length from 45.7 cm. crown-heel length (a premature infant) to 75.7 cm. crown-heel length. All were presumably normal children. They were obtained from (1) the Out-Patient Dispensary at the University Hospital, (2) the Infant Welfare Clinics of Minneapolis, (3) various homes for illegitimate children and (4) hospital boarders. Physically abnormal children were not accepted for measurement.

In collecting the maldeveloped material, only children with complete clefts of both the alveolar process and hard and soft palate (that is, group III according to the Ritchie-Davis classification) were accepted. One exception to this general rule was made; this was a chld with a complete unilateral cleft of the lip and process, but with a normal hard palate and soft palate. Twenty-six abnormal cases were obtained, and two of these were measured twice, with an interval of several weeks between measurements. This makes a total of twenty-eight sets of measurements, and represents the material coming to the University Hospital between January, 1928, and March, 1930, and in addition, eight others who were during this period private patients of Dr. Ritchie. Included in this abnormal material are six females and twenty males, varying in age from a premature infant to a

child 425 days of age and in length from 47.5 cm. crown-heel length (a premature infant) to 75.1 cm. crown-heel length. The maldeveloped material is listed in table 7. The arrangement of this table is according to increasing crown-heel length, for the males, and females, respectively.

DATA LISTED

All data are listed in table 8. Division of the material is here made into normal and maldeveloped children, and each of these groups are divided according to sex. The order of listing is according to increasing crown-heel length. Age in days and weight in grams are included in this table, although they were not utilized in the present analysis of this material.

TABLE 7.—*Maldeveloped Children*

Crown-heel Length, Cm.	Age, Days	Description of Lesion
		Males
47.5	11*	Bilateral complete cleft of lip, process and palate
50.0	10	Right complete cleft of lip, process and palate
50.3†	3	Bilateral complete cleft of lip, process and palate
50.9	58	Left complete cleft of lip, process and palate
51.4	42	Left incomplete cleft of lip; complete cleft of process and palate
51.6‡	16	Right incomplete cleft of lip; complete cleft of process and palate
51.7	47	Right unilateral complete cleft of lip, process and palate
52.0	47	Right unilateral complete cleft of lip, process and palate
52.1	28	Bilateral complete cleft of lip, process and palate
52.3†	25	Bilateral complete cleft of lip, process and palate
52.7	46	Bilateral complete cleft of lip, process and palate
53.6‡	40	Right complete cleft of lip, process and palate
56.8	56	Left incomplete cleft of lip and process;complete cleft of palate
56.9	121	Right complete cleft of lip, process and palate
56.9	21	Left complete cleft of lip, process and palate
57.0	71	Right complete cleft of lip, process and palate
57.8	89	Left complete cleft of lip and process; incomplete cleft of palate
59.0	76	Bilateral complete cleft of lip, process and palate
59.2	101	Right incomplete cleft of lip; complete cleft of process and palate
59.5	110	Bilateral right complete cleft of lip, process and palate; left incomplete cleft of lip, process and palate
63.4	190	Left complete cleft of lip, process and palate
75.1	391	Left complete cleft of lip, process and palate
		Females
52.2	41	Right incomplete cleft of lip; complete cleft of process and palate
52.8	71	Bilateral complete cleft of lip, process and palate
58.9	81	Left complete cleft of lip, process and palate
59.7	95	Left incomplete cleft of lip; complete cleft of process and palate
63.7	246	Right complete cleft of lip, process and palate
66.1	186	Left complete cleft of lip, process and palate

* Premature infant.
† and ‡, same child measured a second time.

ANALYSIS OF DATA

TEST FOR NORMALITY

It is, of course, essential that the dimensions of the cleft palate be compared with the dimensions of the palate in normal children of approximately the same size. To check this, all the material, both normal and abnormal, was compared with a much larger series of normal children (approximately 600) collected by Dr. L. Richdorf.[1] They were

1. Richdorf, L.: A Quantitative Study of Growth of the Normal Infant in the First Year, unpublished thesis for degree of Doctor of Philosophy, University of Minnesota.

TABLE 8.—*Table of Data*

Crown-Heel Length, Cm.	Age, Days	Weight, Gm.	Fronto-occipital Diameter, Cm.	Widest Transverse Diameter of Palate, Cm.	Actual Surface Width of Palate, Cm.	Height of Palate, Cm.	Length of Alveolar Process, Cm.
			Males (Normal)				
49.0	2	3,020	11.1	3.00	3.50	0.72	2.90
49.2	1	3.355	12.3	3.20	3.90	0.93	2.98
49.3	16	3,015	12.0	3.25	3.90	0.97	3.05
51.5	4	3,115	11.7	3.27	3.80	0.94	2.70
51.7	16	3,484	11.7	3.38	3.81	0.96	3.07
52.1	14	3,555	12.6	3.30	3.90	0.98	3.25
52.6	53	3,975	12.5	3.20	3.70	0.81	3.00
52.7	0	3,760	11.2	3.40	3.80	0.81	3.17
52.9	6	3,160	12.2	3.40	3.85	0.80	2.98
53.4	5	4,105	12.1	3.45	4.00	0.80	2.90
53.7	66	4,020	12.5	2.90	3.40	0.71	2.70
54.2	20	3,960	12.6	3.00	3.70	0.94	3.05
54.3	36	4,000	13.5	3.42	4.00	0.86	3.15
54.6	37	4,705	13.1	3.45	4.20	0.85	3.28
56.6	48	4,945	11.7	3.35	4.10	0.96	3.20
56.8	86	4,845	....	3.32	3.90	0.87	3.10
57.9	87	4,760	12.7	3.10	3.80	0.93	2.78
58.9	124	6.170	13.3	3.60	4.20	0.91	3.18
59.0	119	5,675	12.6	3.20	4.30	0.85	3.00
59.0	136	5,595	13.8	3.50	3.65	1.00	3.05
59.3	45	5,429	13.8	3.60	4.30	0.93	3.28
59.9	105	6,790	11.8	3.50	4.25	1.04	3.25
60.1	113	4,750	13.4	3.35	4.00	0.86	3.18
60.4	101	6,505	13 8	3.42	3.80	0.79	3.28
60.5	93	5,670	13.3	3.55	4.35	1.01	3.35
61.7	140	7,045	14.0	3.40	4.00	0.91	3.25
62.9	141	6,255	13.4	3.42	4.22	1.12	3.38
63.6	123	6,805	12.7	3.60	4.00	0.72	3.25
64.1	135	6,275	13.2	3.40	4.02	0.84	3.53
65.1	219	8,340	15.3	3.40	3.90	0.76	3.24
65.7	198	7,300	13.4	3.60	4.17	0.95	3.17
65.7	141	7,810	....	3.70	4.40	0.96	3.55
66.6	168	6,700	12.6	3.70	4.30	0.94	2.95
66.8	225	8,630	14.2	3.60	4.32	1.00	3.36
67.0	179	7,850	12.8	3.60	4.50	1.17	3.00
68.0	286	7,571	14.0	3.50	4.20	0.99	3.41
69.0	313	9,695	14.5	3.70	4.50	1.07	3.58
69.3	238	8,625	15.2	3.60	4.35	1.00	3.20
72.5	330	10,433	15.4	3.40	4.25	1.00	2.85
75.4	259	9,800	16.1	3.60	4.05	0.72	3.33
			Females (Normal)				
45.7	10	2,380	11.1	2.75	3.20	0.84	2.70
48.8	12	2,885	11.7	2.90	3.30	0.72	3.05
49.3	10	3,640	11.7	3.50	3.60	0.85	3.00
50.0	29	3,220	12.5	3.00	3.80	0.85	2.90
50.2	3	3,050	11.5	3.00	3.60	0.80	2.78
50.4	10	2,900	11.4	3.10	3.65	1.04	2.73
51.8	10	3,230	11.6	3.10	3.50	0.77	2.95
52.5	40	3,850	13.7	3.45	3.80	0.84	3.05
52.7	66	3,925	12.4	2.81	3.45	0.87	2.71
53.1	35	3,783	12.6	2.90	3.30	0.72	3.00
53.1	32	3,630	11.5	3.20	3.72	0.81	3.11
55.2	36	3,769	13.0	3.00	3.71	1.13	2.85
55.4	47	3,945	12.1	3.30	3.85	0.87	3.25
55.6	60	4,645	12.4	3.10	3.90	0.97	2.95
56.1	63	5,215	....	3.05	3.65	0.84	3.23
56.3	158	5,475	13.2	3.32	4.40	0.90	3.18
56.3	68	5,144	12.8	3.20	3.65	0.82	2.82
57.3	51	5,600	12.5	3.30	4.00	0.91	3.28
57.5	91	5,130	13.0	3.40	4.00	0.97	3.30
57.9	83	5,157	14.2	3.20	4.00	0.94	3.10
58.2	82	5,606	13.4	3.00	3.70	0.97	3.05
58.5	85	6,105	12.4	3.50	4.10	0.92	2.97
58.7	83	.....	12.3	3.30	3.90	0.99	3.20
59.0	75	5,016	12.5	3.10	3.92	0.97	3.02
59.5	143	6,350	12.6	3.32	3.90	0.91	3.43
60.3	99	5,820	12.2	3.30	4.20	1.11	3.43
60.5	79	4,663	14.1	3.05	3.90	1.11	2.85
60.8	106	5,298	13.0	3.65	4.10	0.96	3.28
61.0	152	6,255	14.8	3.25	4.00	0.90	3.10
61.1	90	4,990	12.7	3.30	4.00	0.91	3.25
61.7	134	5,490	13.8	3.35	3.85	0.89	3.15
61.8	162	6,350	13.8	3.70	4.40	1.07	3.28
61.9	109	6,090	14.4	3.20	3.87	0.97	3.44
62.0	68	5,405	13.5	3.40	4.25	1.09	3.08

compared according to crown-heel length in relation to days in age, using graphic methods. The curves of Richdorf's data drawn through the mean for each month is depicted in figure 9 for the males, and in

TABLE 8.—*Table of Data—Continued*

Crown-Heel Length, Cm.	Age, Days	Weight, Gm.	Fronto-occipital Diameter, Cm.	Widest Transverse Diameter of Palate, Cm.	Actual Surface Width of Palate, Cm.	Height of Palate, Cm.	Length of Alveolar Process, Cm.
			Females (Normal)—Continued				
62.7	115	6,600	14.0	3.00	4.00	1.13	3.25
63.7	176	6,718	14.0	3.50	4.25	0.94	3.25
64.4	259	7,725	15.2	3.40	4.10	1.00	3.25
64.5	100	6,715	13.0	3.42	4.00	0.86	3.44
64.8	203	8,210	....	3.21	3.70	0.74	3.20
65.7	213	6,980	13.6	3.60	4.20	1.04	3.48
66.9	241	7,520	14.4	3.40	3.92	1.08	3.25
68.0	325	8,200	14.2	3.70	4.15	0.93	3.05
68.2	188	7,199	14.9	3.20	3.90	0.88	3.40
68.5	278	7,810	14.7	3.50	4.15	0.94	3.48
69.1	283	8,130	13.7	3.60	4.40	1.06	3.55
70.0	272	8,725	15.3	3.60	4.20	1.05	3.55
70.2	238	7,965	....	3.22	4.00	1.00	3.35
70.7	282	8,630	14.5	3.35	4.15	0.91	2.95
71.5	344	8,190	15.8	3.55	4.35	1.11	3.60
73.8	315	9,010	14.0	3.85	4.52	1.11	3.25
75.5	362	10,020	14.7	3.75	4.55	1.11	3.26

Crown-Heel Length, Cm.	Age, Days	Weight, Gm.	Fronto-occipital Diameter, Cm.	Widest Transverse Diameter of Palate, Cm.	Actual Surface Width of Palate, Cm.	Height of Palate, Cm.	Length of Alveolar Process, Cm.	Width of Cleft, Cm.
			Males (Maldeveloped)					
47.5	11	2,815	11.1	3.70	3.10	1.26	3.30	1.79
50.0	10	3,325	12.5	4.20	3.20	1.23	2.75	1.79
50.3	3	2,900	11.4	3.80	3.90	1.17	3.00	1.40
50.9	58	6,278	12.2	3.60	3.70	1.21	3.00	1.09
51.4	42	3,265	....	4.00	3.20	1.24	3.05	1.20
51.6	16	3,210	11.7	3.70	3.60	1.20	2.95	0.96
51.7	47	4,260	12.6	4.10	4.30	1.54	2.95	0.93
52.0	47	3,729	12.0	4.20	3.55	1.26	3.20	1.35
52.1	28	3,325	12.7	3.60	3.40	1.11	2.75	1.41
52.3	25	3,500	11.1	3.70	3.80	1.18	3.10	1.35
52.7	46	3,480	12.6	3.80	3.60	1.33	2.88	1.42
53.6	40	3,670	13.4	3.70	3.90	1.17	3.10	1.09
56.8	56	4,309	12.5	3.45	3.70	1.18	3.30	0.96
56.9	121	4,500	12.7	4.10	3.50	1.05	3.40	1.34
56.9	21	4,280	12.3	4.10	3.70	1.17	2.85	1.26
57.0	71	4,585	13.7	3.90	4.10	1.26	3.13	1.38
57.8	89	3,645	13.6	3.30	3.90	1.04	3.00	....
59.0	76	4,336	11.9	3.50	3.20	1.10	3.20	1.34
59.2	101	5,225	13.8	3.80	4.00	1.26	3.20	1.23
59.5	110	5,443	14.3	4.30	4.30	1.29	3.50	1.43
63.4	190	5,415	13.8	3.80	3.60	1.09	3.50	1.12
75.1	391	8,845	15.8	3.75	4.30	1.39	3.60	0.87
			Females (Maldeveloped)					
52.2	41	3,933	12.5	3.50	3.75	1.17	3.10	1.10
52.8	71	3,645	12.3	3.60	3.70	1.20	2.85	1.59
58.9	81	3,825	13.1	3.70	3.90	1.16	3.20	1.20
59.7	95	4,705	13.0	3.50	4.00	1.26	2.85	1.07
63.7	246	5,355	12.8	3.60	4.20	1.27	3.30	0.78
66.1	186	5,897	13.0	4.20	4.10	1.09	3.20	1.39

figure 10 for the females. Three times the probable errors of the means is indicated in each figure. Field graphs of the length with age of the present study are included in each figure, a difference in symbol indicating whether normal or maldeveloped. The children of this series are seen to be slightly smaller than those collected by Richdorf, especially

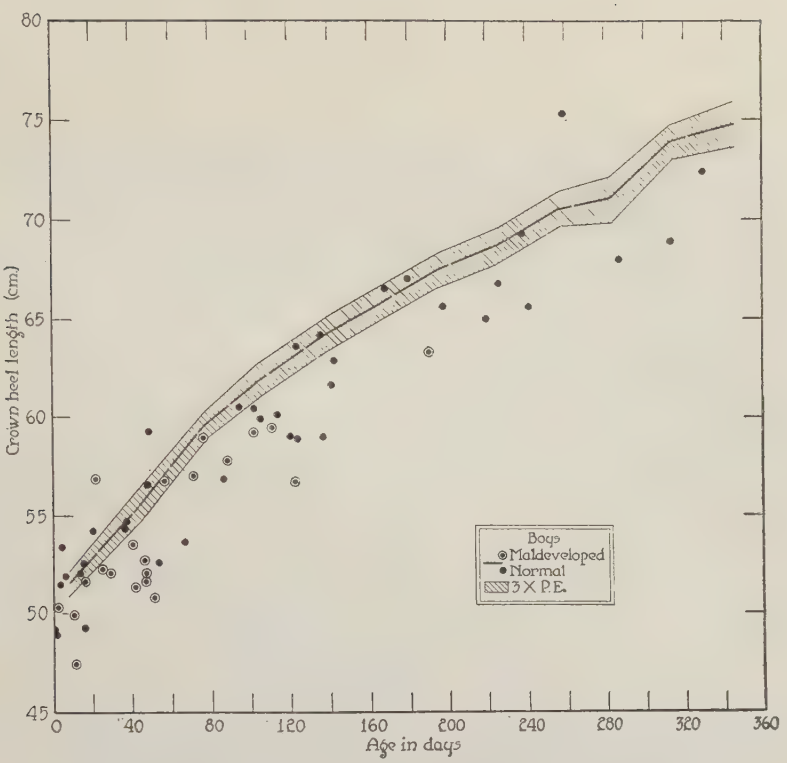

Fig. 9.—The curve of Richdorf's data for male children drawn through the mean for each month and field graphs of the length with age of the male children of the present study.

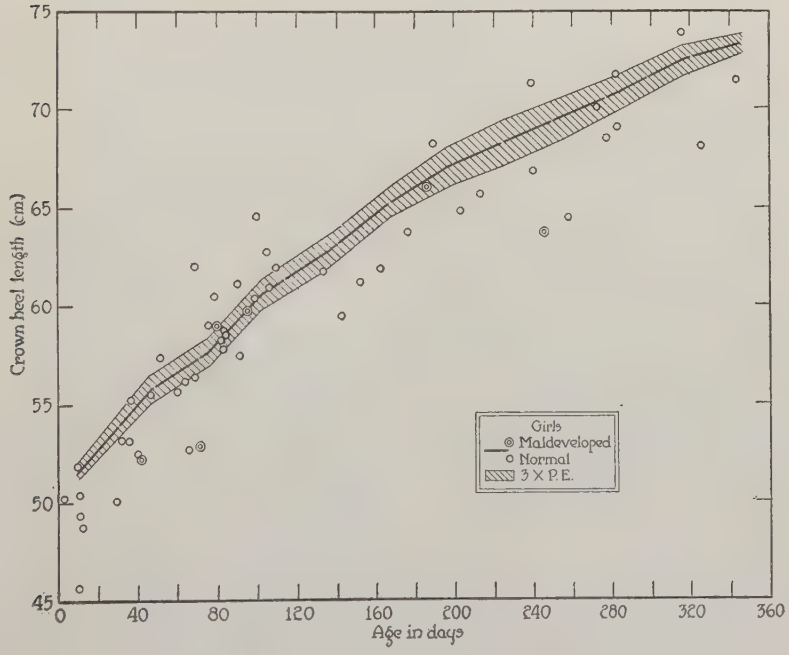

Fig. 10.—The curve of Richdorf's data for female children drawn through the mean for each month and field graphs of length with age for the female children of the present study.

is this true of the male children. The maldeveloped children, however, are approximately the same length for age and sex as the normal children of this series.

The question then arose whether or not the difference in length of males and females for the same age necessitated treating them separately according to sex. In a series as small as this it would be advantageous to combine boys and girls. In the pathologic series the males predominate approximately as 4.5 : 1, but in the normal material the females predominate as 5 : 4. Although in infancy, the female is smaller than the male, her bodily proportions are approximately the same. If this general rule holds for these data, they could be analyzed without regard to sex. For instance, if males and females of the same length have the same sized heads, the sex differences in length for age could be eliminated by using length instead of age as a base. To test this supposition, the trends of the fronto-occipital diameter with length were fitted by the method of least squares for both the normal boys and girls. This is the general method used throughout this study.[2]

Field graphs of the fronto-occipital diameter of the head with body length and their fitted trend are depicted in figure 11. The measures for male and female children are depicted in separate graphs with

---

2. D = difference between calculated and observed value of Y.

$$Y = BX + A$$
$$BX + A - Y = D$$
$$F = (BX + A - Y)\Sigma = \text{a minimum}$$

Differentiating with respect to B. $\frac{DF}{DB} = \Sigma(BX + A - Y)X = O$

Differentiating with respect to A. $\frac{DF}{DA} = \Sigma(BX + A - Y)1 = O$

Now solve the foregoing two simultaneous equations for B and A.

(1) $\Sigma X^2B + \Sigma XA - \Sigma YX = O$

(2) $\Sigma XB + \Sigma A - \Sigma Y = O$

(3) $\Sigma XY = \Sigma X^2B + \Sigma XA$

From (2) since $\Sigma A = NA$ where (4) $\Sigma Y = \Sigma XB + NA$

N = number of observations

Multiply (3) by $\frac{1}{\Sigma X}$ (5) $\frac{\Sigma XY}{\Sigma X} = \frac{\Sigma X^2B}{\Sigma X} + A$

Multiply (4) by $\frac{1}{N}$ (6) $\frac{\Sigma Y}{N} = \frac{\Sigma XB}{N} + A$

Subtracting to solve for B. $\frac{\Sigma XY}{\Sigma X} - \frac{\Sigma Y}{N} = \frac{\Sigma X^2B}{\Sigma X} + A - \frac{\Sigma XB}{N} - A$

$$\frac{\Sigma XY}{\Sigma X} - \frac{\Sigma Y}{N} = B\left[\frac{\Sigma X^2}{\Sigma X} - \frac{\Sigma X}{N}\right]$$

$$B = \frac{\frac{\Sigma XY}{\Sigma X} - \frac{\Sigma Y}{N}}{\frac{\Sigma X^2}{\Sigma X} - \frac{\Sigma X}{N}}$$

From (6) $A = \frac{\Sigma Y}{N} - \frac{\Sigma XB}{N}$

their respective straight line trends. For the purpose of comparison the fitted trends of the data for females and males are depicted in figure 25. The trends for both sexes practically coincide, demonstrating no essential sex differences in the size of the head. For this reason, most of the comparisons of maldeveloped cases with the normal have been made without regard to sex.

DIVISION OF DATA

The data for normal and abnormal material have each been divided according to sex for further comparisons in the study of certain dimensions of the palate, namely, the widest transverse diameter of the

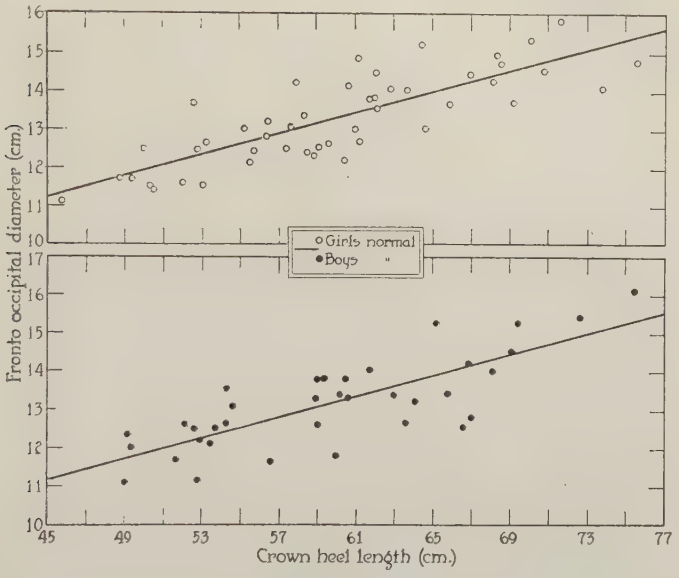

Fig. 11.—Field graphs and trend of the fronto-occipital diameter with body length of the female and male children of this study.

palate, actual surface width of the palate and height of the palate. After these various divisions of the material were made, a straight line was fitted to the measurements of each group by the method of least squares. The root mean square or standard deviation, probable error, and the probable error of the trend were computed for each group.[3] The result of these computations are recorded in table 9.

3. Standard deviation: $\sigma = \sqrt{\frac{\Sigma\Delta^2}{N}}$

Probable error: $P.E. = 0.6745\sigma$

Bowley: Elements of Statistics, ed. 4, London, P. S. King & Son, 1920, p. 270.

Probable error of the trend: $P.E.T. = \frac{P.E.}{\sqrt{N}}$

Kelley: Statistical Method, New York, The Macmillan Company, 1923, p. 105.

TABLE 9.—*Table of Formulas*

Dimension	Data Included	Number of Observations	Formula	Root Mean Square Deviation, Cm.	P. E.	P. E.m	Average Deviation	Average per Cent Deviation
Fronto-occipital diameter	Combined male, female (normal)	86	$y = 5.067 + 0.136\ L$	0.677	0.457	0.049	0.553	4.06
	Combined male, female (maldeveloped)	27	$y = 5.495 + 0.129\ L$	0.641	0.432	0.083	0.537	4.50
	Male (normal)	38	$y = 4.958 + 0.137\ L$	0.692	0.467	0.075	0.565	3.64
	Female (normal)	48	$y = 5.106 + 0.136\ L$	0.662	0.447	0.065	0.550	4.12
Widest transverse diameter of palate	Combined male, female (normal)	91	$y = 2.025 + 0.022\ L$	0.181	0.122	0.013	0.148	4.48
	Combined male, female (maldeveloped	28	$y = 3.799 - 0.0001\ L$	0.260	0.168	0.032	0.214	5.64
	Male (normal)	40	$y = 2.216 + 0.020\ L$	0.146	0.098	0.016	0.117	3.43
	Female (normal)	51	$y = 1.787 + 0.025\ L$	0.183	0.123	0.017	0.142	4.33
	Male (maldeveloped)	22	$y = 4.100 - 0.005\ L$	0.263	0.177	0.038	0.210	5.50
	Female (maldeveloped)	6	$y = 1.857 + 0.031\ L$	0.197	0.128	0.052	0.148	3.94
Actual surface width of palate	Combined male, female (normal)	91	$y = 2.181 + 0.030\ L$	0.205	0.138	0.015	0.165	4.17
	Combined male, female (maldeveloped)	28	$y = 1.905 + 0.033\ L$	0.282	0.190	0.036	0.218	5.85
	Male (normal)	40	$y = 2.483 + 0.026\ L$	0.197	0.133	0.021	0.166	4.12
	Female (normal)	51	$y = 1.829 + 0.035\ L$	0.193	0.130	0.018	0.150	3.84
	Male (maldeveloped)	22	$y = 2.157 + 0.028\ L$	0.320	0.216	0.046	0.250	6.76
	Female (maldeveloped)	6	$y = 2.116 + 0.031\ L$	0.067	0.045	0.018	0.053	1.34
Height of palate	Combined male, female (normal)	91	$y = 0.570 + 0.006\ L$	0.101	0.068	0.007	0.079	1.44
	Combined male, female (maldeveloped)	28	$y = 1.221 - 0.0002\ L$	0.100	0.068	0.013	0.073	6.02
	Male (normal)	40	$y = 0.672 + 0.004\ L$	0.105	0.071	0.011	0.085	0.93
	Female (normal)	51	$y = 0.403 + 0.009\ L$	0.093	0.063	0.009	0.073	7.55
	Male (maldeveloped)	22	$y = 1.176 + 0.0007\ L$	0.114	0.077	0.016	0.083	6.80
	Female (maldeveloped)	6	$y = 1.310 - 0.002\ L$	0.068	0.046	0.019	0.053	4.49
Length of alveolar process	Combined male, female (normal)	91	$y = 2.015 + 0.019\ L$	0.179	0.121	0.013	0.145	4.61
	Combined male, female (maldeveloped)	28	$y = 1.824 + 0.023\ L$	0.176	0.114	0.022	0.135	4.36
Width of cleft	Combined male, female	27	$y = 2.622 - 0.018\ L$	0.222	0.150	0.029	0.177	13.80

ANALYSIS OF THE DIFFERENCE BETWEEN NORMAL AND CLEFT PALATES

The measurements of the normal child and the abnormal child were graphically compared. The method was similar for each set of dimensions. A field graph of the palate measurements of the normal children with body length is presented with their fitted trend and three times its probable error. Field graphs of the measurements of the abnormal children with body length is also presented with their fitted trend and three times its probable error. For purposes of comparison, the fitted trends of the normal and abnormal children are depicted in figure 25 in their actual relation to each other.

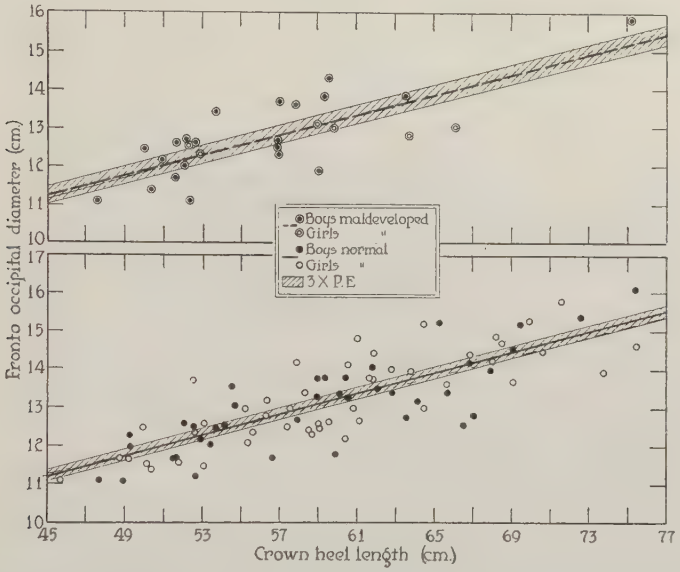

Fig. 12.—Field graphs of the fronto-occipital diameter with body length for the abnormal children and for the normal children. The fitted trend and three times the probable error is indicated in each graph.

Fronto-Occipital Diameter.—The fronto-occipital diameter of the normal children is compared with the same dimensions of the maldeveloped children in figure 12. A field graph of the fronto-occipital diameter of the normal children with body length is presented with their fitted trend and three times its probable error. A field graph of the fronto-occipital diameter of the abnormal children with body length is also presented with its fitted trend (indicated in broken line) and three times its probable error. For the purpose of comparison, the fitted trends of the normal and abnormal children are depicted in

figure 25. It is evident that there is no significant difference in the fronto-occipital diameter in these two groups, their trend falling well within the range of three times the probable error. The size of the head is therefore approximately the same for the normal, as for the maldeveloped material.

Surface Width of the Palate.—The surface width of the normal palate is compared with that of the cleft palate in figure 13. Field graphs of both the normal and maldeveloped children are depicted. The range of three times the probable error of the trend is indicated in each field graph. For the purpose of comparison, the lines of trend for both groups of data are depicted in figure 25. Growth is definitely indicated, but it is doubtful if there is a significant difference in the surface width of the palate in the normal and maldeveloped children. An increment is demonstrated of approximately 8 mm. in the surface

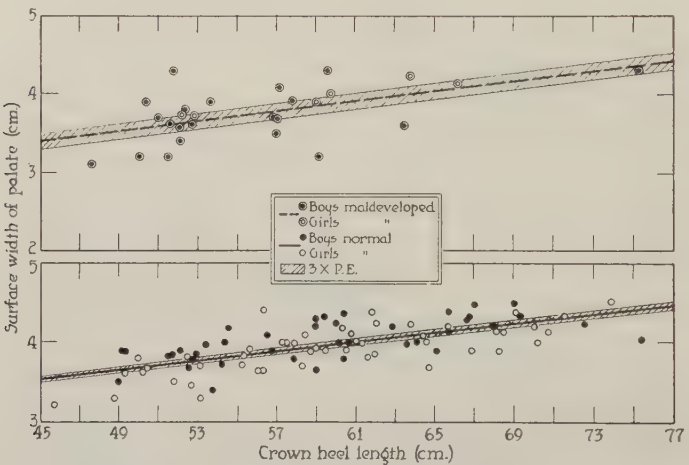

Fig. 13.—Field graphs of the surface width of the palate with body length for the abnormal children and the normal children. The fitted trend and three times the probable error is indicated in each graph.

width of the normal palate during that portion of the growth period included in this study, and a very similar amount of growth in the cleft palate. The fitted line of trend for the maldeveloped material for 51 cm. length is approximately 1.3 mm. less than that for the normal material and at 59 cm. length it is 1 mm. less. The foregoing points, 51 and 59 cm., are chosen because the majority of the maldeveloped material is included within this length. This apparent difference in surface width is probably not significant. It may be due to greater difficulty in getting the end-point of measurement at the medial edge

of the cleft palate, or it may be the result of chance selection in the small group of the maldeveloped children. That chance selection is a cause for this difference is supported by analysis of the same data when divided according to sex. Field graphs of the data for males and

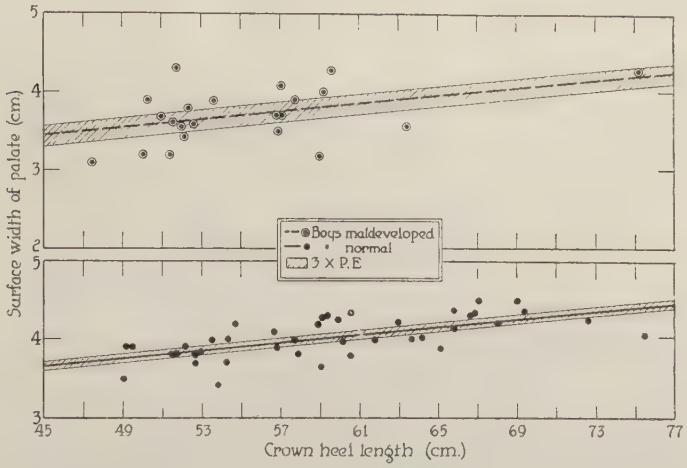

Fig. 14.—Field graphs of the surface width of the palate with body length for the abnormal and normal boys of this series. The fitted trend and three times the probable error is indicated in each graph.

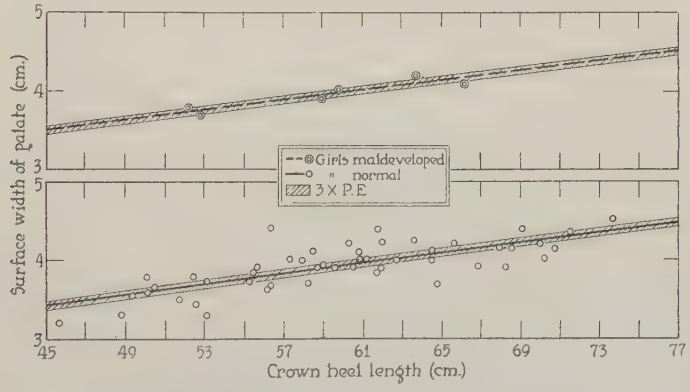

Fig. 15.—Field graphs of the surface width of the palate with body length for the abnormal and normal girls of this series. The fitted trend for each group of data and three times the probable error is indicated in each graph.

females are depicted in figures 14 and 15, respectively. Their lines of trend and the range of three times the probable error are indicated. For the purpose of comparison, the line of trend of each group of normal

data is depicted in figure 25 in its actual relation to the fitted trend of the abnormal material of the same sex. The fitted trend of the abnormal male children at 51 cm. length is approximately 2.5 mm. below that of the normal male children and at 59 cm. length it is approximately 2 mm. below that of the normal children, while on the other hand, the fitted trend of the maldeveloped females indicates a wider actual surface width in the cleft than in the normal palate.

Widest Transverse Diameter of the Palate.—The widest transverse diameter of the palate is depicted in figure 16, in which field graphs of the normal children and the maldeveloped children are presented with the trend for each group of data. Three times the probable error of the

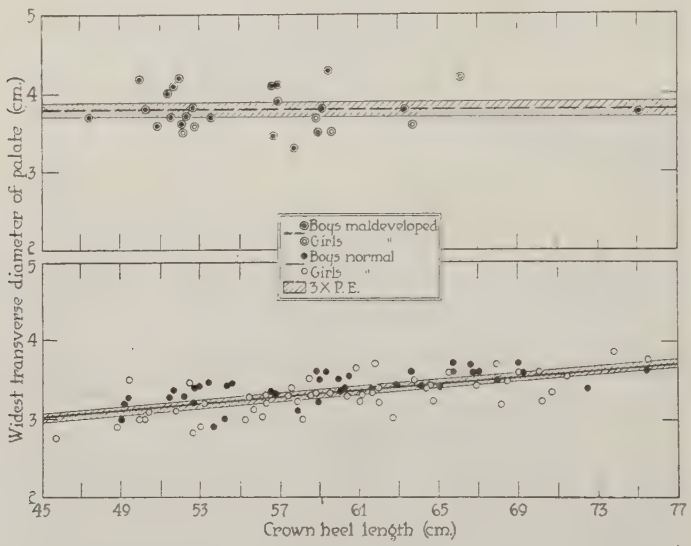

Fig. 16.—Field graphs of the widest transverse diameter of the palate with body length for the abnormal and normal children of this series. The fitted trend and three times the probable error is indicated in each graph.

fitted trend is indicated in each field graph. For the purpose of comparison, the fitted trend of each group of data is depicted in figure 25. Definite growth and also significant difference in the widest transverse diameter between the normal and the cleft palate is indicated. Approximately 6 mm. increase in width of the normal palate during the period of growth included in this study is demonstrated but no increase in the width of the cleft palate. Since the fitted line of trend for the cleft palate shows no spread or increase of the width of the maxillae during the period included in this study, therefore, if this material is representative, any growth which does occur is toward the midline. This would

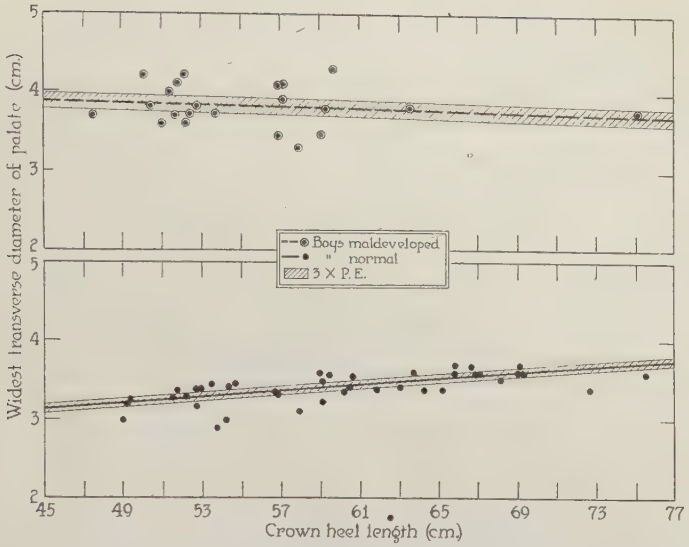

Fig. 17.—Field graphs of the widest transverse diameter of the palate with body length for the abnormal and normal male children. The fitted trend and three times the probable error is indicated.

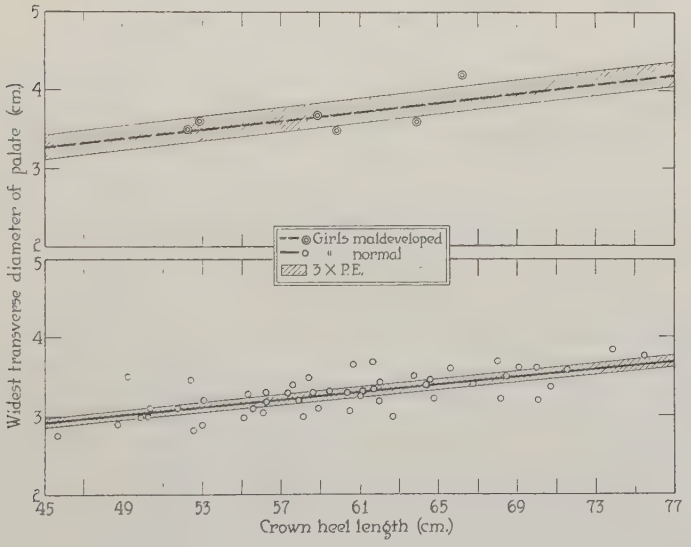

Fig. 18.—Field graphs of the widest transverse diameter of the palate with body length for the abnormal and normal female children. The fitted trend and three times the probable error is indicated in each graph.

lead one to expect that the cleft would become narrower as growth occurred in the palate. To check this, the width of the cleft was measured, and analysis of these measurements confirmed this supposition (fig. 23). This is the most unexpected and remarkable observation demonstrated in this study. That the transverse diameter of the cleft palate is greater than the transverse diameter of the palate of the normal child of equal body length is evident. The difference in width at the 51 and 59 cm. lengths is approximately 7 and 5 mm., respectively. With the data grouped according to sex, field graphs and their trend for measures of the widest transverse diameter of the cleft and normal palate are depicted in figures 17 and 18 for male and female children respectively. For the purpose of comparison, the line of trend for the measures of male children, normal and abnormal, are depicted in

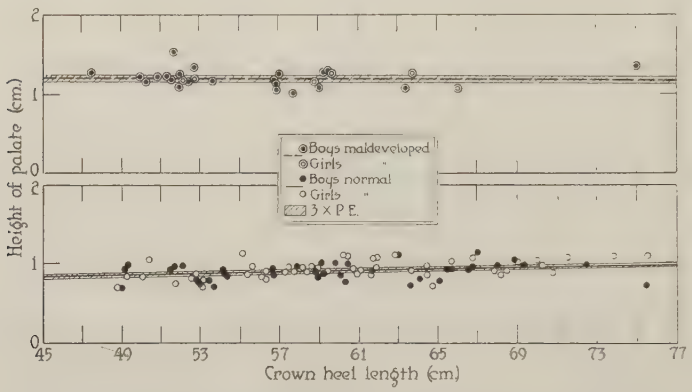

Fig. 19.—Field graphs of the height of the palate with body length for the abnormal and normal children of this series. The fitted trend and three times the probable error is indicated in each graph.

figure 25 in their actual relation to each other, and the lines of trend for the measures of the female children are also depicted in similar manner in figure 25. As a whole, the results are similar to those in which no division as to sex was made.

Height of Palate.—Comparison of the height of the palate is depicted in figure 19, which is composed of field graphs and their trends for the measures of normal children and the maldeveloped children. Three times the probable error of the trends is indicated in each field graph. For the purpose of comparison, the trends of each group is depicted in figure 25. There is little increase in height during the period studied, approximately 1 mm. for the normal palate and no increase for the cleft palate. That the cleft palate is definitely higher than the normal palate of children of the same body length, is demonstrated. At 51 cm. crown-

heel length, the trend for the maldeveloped material is approximately 3 mm. higher and at 59 cm. length 2.5 mm. higher. With the data grouped according to sex, field graphs and their trend for measures of the height of the normal palate and the cleft palate are depicted in figures 20 and 21 for the males and females, respectively. Three times

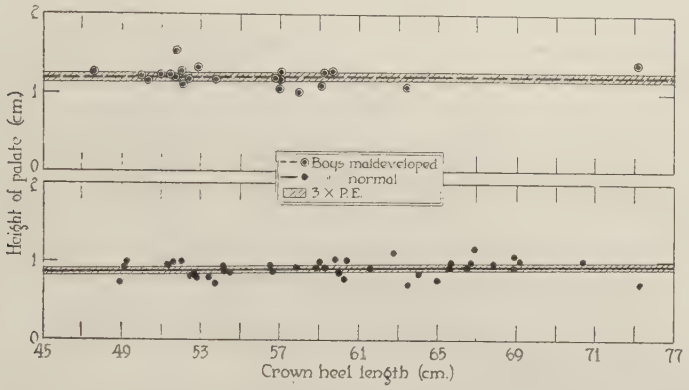

Fig. 20.—Field graphs of the height of the palate with body length for the abnormal and normal male children. The fitted trend and three times the probable error is indicated in each graph.

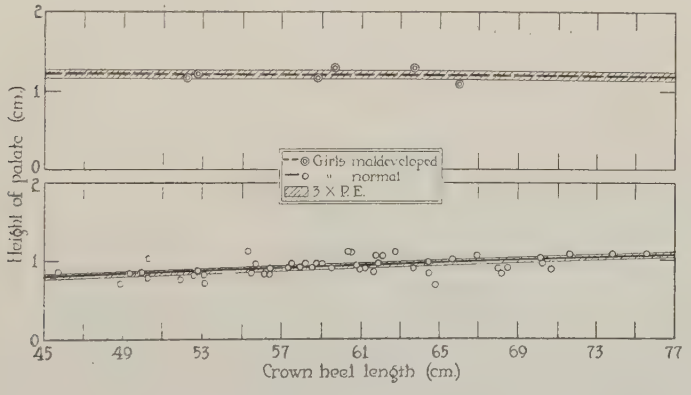

Fig. 21.—Field graphs of the height of the palate with body length for the abnormal and normal female children. The fitted trend and three times the probable error is indicated in each graph.

the probable error of the fitted trends for each group is depicted. For the purpose of comparison, the lines of trend for measures of the male children, normal and abnormal, are depicted in figure 25 in their actual relation to each other, and the lines of trend for measures of the female

children are also depicted in similar manner in figure 25. In general, the result is similar to that for the combined data.

Length of the Alveolar Process.—The values determined for length of the alveolar process in the maldeveloped children were divided into three groups: the long side, the short side and the average of both sides in a case of bilateral cleft. There were twenty in each of the first two groups and eight in the latter. The arithmetical mean of each of these groups of dimensions was taken. For the long side it was 3.05 cm.; for the short side, 3.11 cm., and 3.08 cm. for the average length of the bilateral cleft palates. This reveals a discrepancy of less than 1 mm., which is within the possible error of measurement.

The length of the alveolar process of the palate is depicted in figure 22, which consists of field graphs and their line of trend for the

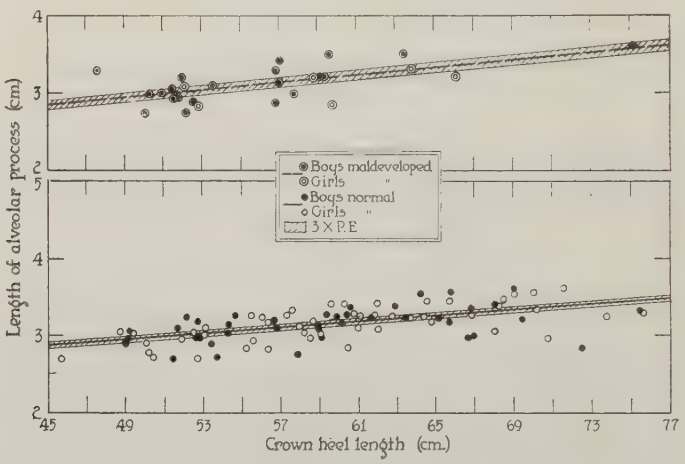

Fig. 22.—Field graphs of the length of the alveolar process with body length for the abnormal and normal children. The fitted trend and three times the probable error is indicated in each graph.

measures of the normal children and the maldeveloped children. Three times the probable error of the fitted trends is indicated in each field graph. For the purpose of comparison, the lines of trend of each group of data is depicted in figure 25.

Growth in length of the alveolar arc of the normal palate is approximately 5 mm. during the period included in these data, and as much, if not slightly more, in the alveolar arc of the cleft palate.

Although, on the whole, in the maldeveloped children the fitted trend for length of the alveolar process with body length is slightly above that of normal children, it does not appear to be a significant difference. In that portion of the graph which includes most of the

maldeveloped material, namely, from 51 to 59 cm. crown-heel length, it is not greater than 0.5 mm. It is possible that some of this difference in length is due to the difference in the method of obtaining these dimensions. The normal palate was measured directly as the chord of the arc of one side of the alveolar process. The maldeveloped palate was measured for the most part as two segments or chords, the sum of whose circumference represented the entire alveolar arc, that is, the arc of the maxillary portion of the alveolar border and one-half the premaxilla were summated to obtain the length of the alveolar arc. Since the sum of two chords is greater than the chord of the sum of the circumference they represent, this probably is a slight source of error in the direction indicated by the lines of trend.

Width of the Cleft.—Since analysis of the widest transverse diameter of the palate demonstrated an increase of approximately

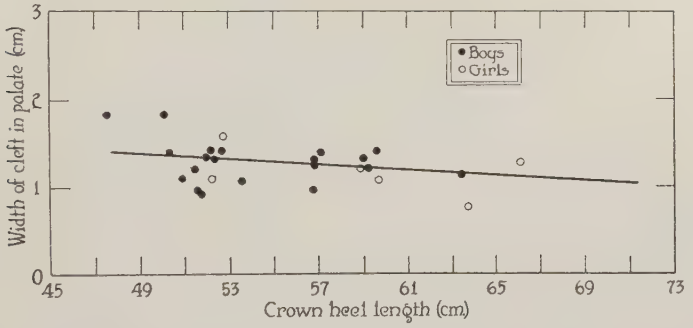

Fig. 23.—A field graph of the width of the cleft with body length. The fitted trend is indicated.

7 mm. in the first year and no increase in the same dimension of the cleft palate during this same period, although there was growth in the palate of both the normal and abnormal children, as demonstrated by the actual surface measurement, it should follow that the cleft becomes smaller or more narrow during the period of growth included in this investigation. This supposition is supported by analysis of measures of the cleft. A field graph of the width of the cleft and its line of trend is depicted in figure 23. Between the extreme ends of the graph it diminishes approximately 4 mm. The material is so variable that this may be a chance selection of wide clefts in the smaller specimens, but since it checks so well with the other observations it is more probable that there is actual growth of the tissues toward the midline. This can be checked by repeated measurements on the same child over a period of several months.

COMMENT

Comparison of the results of this investigation with the dimensions of the palate, as determined by other investigators, cannot be accurately made, since their results have not been analyzed in this manner, the age distribution of material does not correspond, and the method of taking and the end-points of measurements are not the same. In general, however, there is a similarity of results. In table 10 are recorded the results of investigators quoted in the section on literature and included are those of this investigation for comparison.

Congenital malformations of the upper lip and palates are most common in boys. Haug reported that in 2,352 instances of such maldevelopment the male was effected in 64.3 per cent. Davis reported 24 children with clefts, 71 per cent of whom were boys. In this series there were 20 boys and 6 girls, or 77 per cent males and 23 per cent females.

TABLE 10.—*Dimensions of the Palate Compared with Results of Other Investigators*

Investigator	Dimension		
	Width, Cm.	Height, Cm.	Length, Cm.
Alkan (average)	2.70	1.20	3.20
Denzer (average)	3.09	0.88	....
Franke (average)	....	....	2.68
This study (median)	3.30	0.95	3.15

Congenital clefts of the upper lip and upper part of the face are most common on the left side. Haug reported 2,238 cases with left-sided cleft in 50.9 per cent, right-sided in 21.8 per cent and bilateral in 27.3 per cent. In general, only complete clefts are included in the series of this investigation and are not entirely comparable, therefore, with this report of Haug where all clefts were included. This may be the reason in part for the difference in frequency in this series, namely, left-sided cleft, 38 per cent; right-sided cleft, 35 per cent and bilateral cleft, 27 per cent.

The results of this investigation would, of course, have been more conclusive if the maldeveloped material was represented by a larger series. Anomalies of the upper part of the face and jaw are not of frequent occurrence. They occur in colored people once in 1,788 births and in white people once in 915 births, according to the figures of Davis who reviewed the birth records of 28,085 consecutive deliveries in which there occurred 24 instances of cleft. Frobelius, in 1865, reported 76 instances of cleft in 180,000 hospital admissions, or approximately

1 to every 2,400. Since complete clefts, unilateral or bilateral, were chosen for the present study, many cases with lesser degrees of cleft were rejected. Complete clefts, unilateral or bilateral, occurred in 73.4 per cent of 1,887 cases of clefts of the lip and palate reported by Haug, 24 per cent of which were complete bilateral clefts of the lip, process and palate.

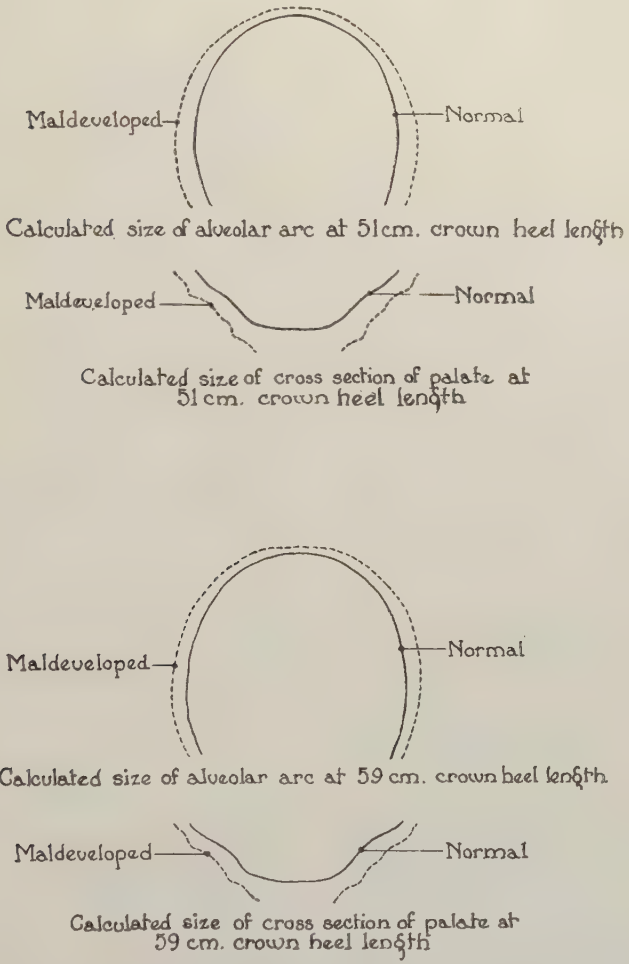
Maldeveloped
Normal
Calculated size of alveolar arc at 51 cm. crown heel length
Maldeveloped
Normal
Calculated size of cross section of palate at 51 cm. crown heel length
Maldeveloped
Normal
Calculated size of alveolar arc at 59 cm. crown heel length
Maldeveloped
Normal
Calculated size of cross section of palate at 59 cm. crown heel length

Fig. 24.—An outline of the alveolar process and a cross-section of the palate depicting, as determined in this study, the relative size of the abnormal and normal palate at 51 cm. crown-heel length and 59 cm. crown-heel length.

Other problems in connection with surgical measures on maldevelopments of the upper lip and palate could be solved by this method, especially should the anatomic results of operations be investigated.

SUMMARY

Growth increments of the normal palate during approximately the first year (from 49 to 75 cm. crown-heel length) are as follows:

Widest transverse diameter of palate	5.5 mm.
Actual surface width of palate	8.0 mm.
Height of palate	1.0 mm.
Length of alveolar process	5.0 mm.

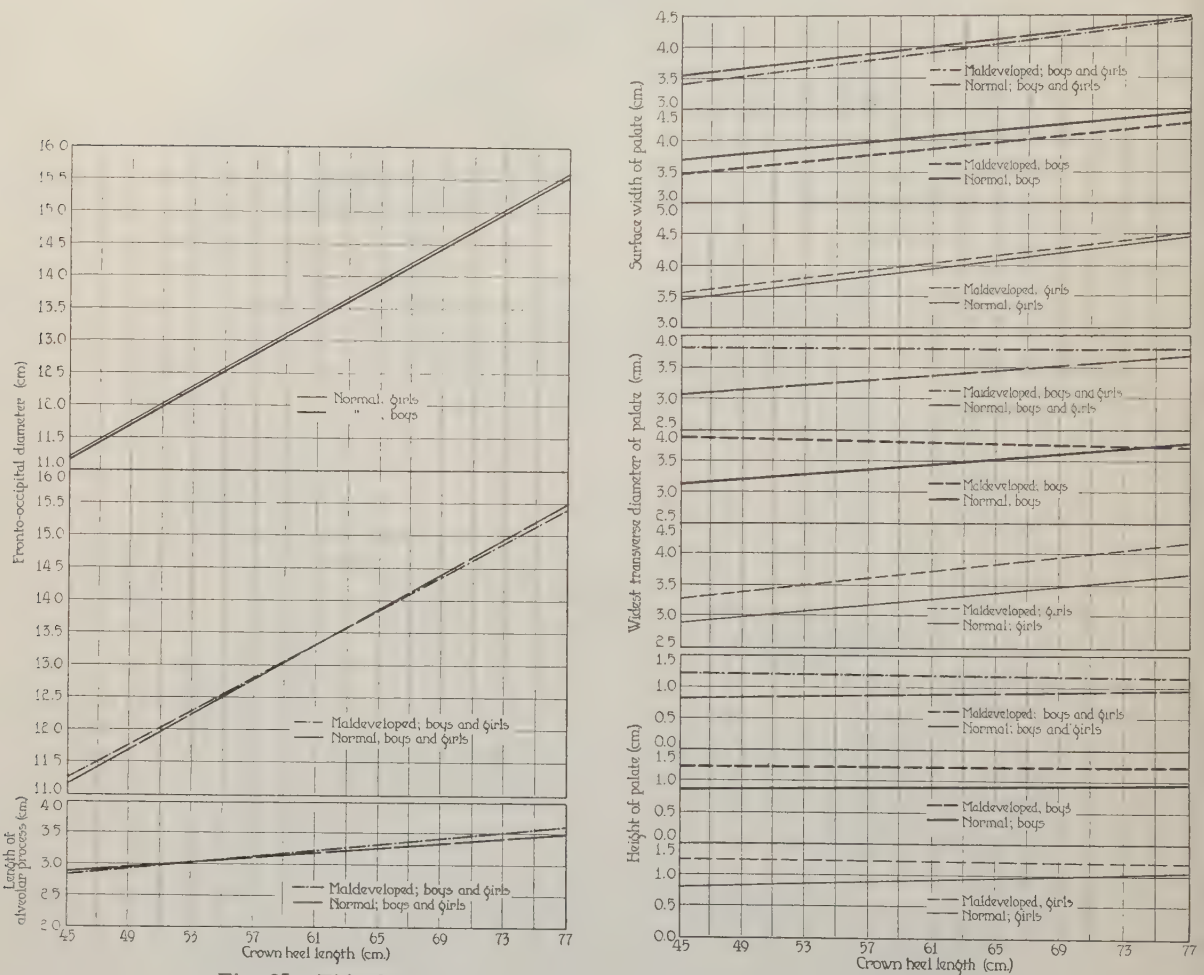

Fig. 25.—This figure illustrates the relation of the trends of (*a*) the surface width of the palate with body length, (*b*) the widest transverse diameter of the palate with body length, (*c*) the height of the palate with body length, (*d*) the fronto-occipital diameter of the head with body length, and (*e*) the length of the alveolar process of the palate with body length.

Dimensions of cleft palate, except surface width, are larger than those of the normal palate. The cleft palate dimensions compared with those

of the normal palate for children of 51 and 59 cm. crown-heel length, respectively, are as follows:

	51 cm. crown-heel length, mm.	59 cm. crown-heel length, mm.
Widest transverse diameter of palate.....	+7.0	+5.0
Actual surface width of palate.....	—1.3	—1.0
Height of palate	+3.0	+2.5
Length of alveolar process.....	0.0	+0.5

These differences in the size of the cleft palate and the normal palate are graphically represented in figure 24.

The width of the cleft was found to diminish 1.5 mm. during the growth interval between 51 and 59 cm. crown-heel length. This was to be expected, after it was found that the widest transverse diameter during the same interval remained approximately unchanged.

To Dr. Harry P. Ritchie and Dr. Edith Boyd I wish to express appreciation. Dr. Ritchie has offered many helpful suggestions during the preparation of this thesis. He has made it possible to obtain cleft palate material in quantity and assisted in the collection of most of the abnormal material.

Dr. Boyd has offered many helpful suggestions in the analysis of these data.

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